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The Evolution of U.S. Nuclear Weapons Design: Trinity to King (U)

Lawrence S. Germain

January 2, 1991

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January 2, 1991

The Evolution of U.S. Nuclear Weapons Design: Trinity to King (U)

Lawrence S. Germain

[redacted]

[redacted]

[redacted]

CNSS
Center for National Security Studies
Los Alamos National Laboratory

[redacted]

Lawrence S. Germain retired from the Los Alamos National Laboratory in 1985 after thirty years of experience in weapons design and testing in the national laboratories—twenty years at Lawrence Livermore National Laboratory and ten years at Los Alamos. He received a Ph.D. in physics from the University of California, Berkeley, in 1949 and taught physics for four years at Reed College, Portland, Oregon, before joining Livermore. Much of this report is drawn from the author's memory, and many of the opinions expressed reflect his personal recollections.

The first draft of this report was written in 1988, and the information in the report does not reflect events or research since 1988.

CONTENTS

PREFACE

This report is one in a CNSS series that surveys the development of nuclear weapons over the past forty-five years. The unifying themes throughout the series are the technical advances and failures associated with new weapon systems, and the creation of the stockpile.

Authors, titles, and report numbers are listed below.

William G. Davey, *Free-Fall Nuclear Bombs in the U.S. Stockpile (U)*, LA-11397

William G. Davey, *Nuclear Tests Related to Stockpiled Weapons Development (U)*, LA-11402

Lawrence S. Germain, *A Brief History of the First Efforts of the Livermore Small-Weapons Program (U)*, LA-11404

Lawrence S. Germain, *The Evolution of U.S. Nuclear Weapons Design: Trinity to King (U)*, LA-11403

Lawrence S. Germain, *A Review of the Development of Los Alamos Gnats and Tsetses before the 1958 Test Moratorium (U)*, LA-11749

Raymond Pollock, *The Evolution of the Early Thermonuclear Stockpile (U)*, LA-11748

Raymond Pollock, *A Short History of the U.S. Nuclear Stockpile 1945–1985 (U)*, LA-11401

(All reports are classified Secret Restricted Data)

January 2, 1991

THE EVOLUTION OF U.S. NUCLEAR WEAPONS DESIGN: TRINITY TO KING (U)

Lawrence S. Germain

ABSTRACT (U)

This report, one in a series concerned with the history of nuclear weapons research and development, examines the evolution of U.S. nuclear weapons design. The approach is to judge the status of weapons development by examining the finished product: designs that were deemed worthy of nuclear testing and systems that were placed in stockpile. The paper, therefore, alternates between discussions of advancement in nuclear weapons technology as seen in nuclear tests and discussions of the growth in numbers and kinds of explosives in stockpile.

INTRODUCTION

In the fission process, a neutron is captured by the nucleus of a fissile material, causing the nucleus to split into two approximately equal fragments and in the process releasing considerable energy and more neutrons. These neutrons may meet several fates: capture by a nonfissile nucleus, capture by a fissile nucleus that does not produce a fission, or escape from the fissile material. Or the neutrons may produce another fission. If on the average one neutron produced by a fission produces a second fission, a continuing chain of fissions (a chain reaction) and a continuing release of energy will occur. If on the average more than one neutron from a fission produces fissions in turn, conditions exist for a rapid growth of the fission process and an explosive release of energy.

To achieve a nuclear explosion, neutron losses must be minimized so that more than one neutron from a fission will produce fissions. Escape from the fissile material is the most easily controlled neutron loss because it is just a matter of geometry. Leakage from a system is decreased when the surface-to-volume ratio is decreased. The geometry with the minimum surface to volume is a sphere. [redacted] The surface-to-volume ratio also decreases as the size of the system is increased. This leads to the concept of a critical size (or critical mass), where the neutron losses are reduced to a point at which a chain reaction can be maintained.

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A nuclear explosion will occur when a supercritical mass of fissile material is rapidly created. The simplest concept is to assemble two subcritical masses into a single supercritical mass. This is the concept of the gun-assembled weapon. Another concept is to suddenly reduce the critical mass of the system by suddenly reducing the leakage of neutrons from the system. There are two ways to do this: reflection and compression, and both are used in implosion weapons. In the first method, a material (a reflector) is placed around the fissile material to scatter some of the escaping neutrons back into the fissile material. Compression, the second method, decreases the size of a sphere of fissile material; therefore, the atoms are packed closer together, and the fissile material looks bigger to the neutron because it is more probable that the neutron will suffer a collision before reaching the surface. The gains from compression can be accurately stated: if the entire system is compressed, the critical mass is reduced by the inverse square of the compression. For example, if a uniform compression of two were achieved, the critical mass would be reduced by a factor of 4.

From 1945 through 1952, implosion systems were designed to do one or more of the following: rapidly compress fissile materials, rapidly assemble fissile materials, and rapidly assemble the reflector onto the fissile material. The energy to accomplish these processes came from high explosive (HE), which has the desirable property of high energy per unit volume and the even more important capacity to release energy rapidly.

The implosion process started with the simultaneous firing of several detonators. These detonators lit HE lenses, producing a spherically converging detonation front that, in turn, lit an inner HE charge. (The HE charge was a spherical shell.) The pressure pulse from the HE pushed on inner spherical shells of metal, and the spherically converging shock wave finally converged on a central ball containing fissile material.

The vital step is to convert chemical energy of the HE into compressional energy of the fissile material; therefore, the efficiency with which the HE delivers energy into the central components of the system is critical. This energy is delivered by means of the high-pressure gases produced by the HE detonation pushing on the inner shells of metal. Two factors affecting the energy delivery to the metal shells are how rapidly the pressure pulse decays with time and how far the HE pushes the metal shells. The pressure pulse can be maintained for longer times by having a relatively thick layer of HE. How far the HE can push the metal shells will depend on the details of the design, but designs that can maximize this distance will be more efficient.

An implosion system necessarily performs very quickly. In the systems tested from 1945 through 1952, supercriticality was reached before the spherically converging shock wave reached the center of the device. In principle, a stray neutron could trigger a nuclear explosion at any time after achieving supercriticality, but the probability of this occurring is low because of the short time scale and the relatively rare appearance of a stray neutron. However, to ensure a nuclear explosion, neutrons must be present to initiate the reaction, and they must be present at the right time. Accordingly, supplying a neutron source was essential. In most cases, this source was located in the center of the system and activated by the shock reaching the center.

TRINITY

The Trinity test was carried out on July 16, 1945. [redacted]

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The terms tamper and pusher describe quite well the role that these components play in the implosion design. [redacted]

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[redacted] (To tamp means to fill up above a blasting charge, to confine, and make the charge more effective.) The purpose of the heavy tamper was to provide inertia to hold the system together for a maximum time while the nuclear reaction proceeded, thus producing a maximum yield before the system disassembled and became subcritical. An important aspect of nuclear explosions is the race between nuclear energy production and disassembly that results in subcriticality and the cessation of energy production. [redacted] The nuclear reaction of the Trinity device was initiated by an Urchin initiator that produced neutrons by an (α,n) reaction on beryllium. [redacted]

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HIROSHIMA

Chronologically, the first nuclear detonation after Trinity was the combat air drop of the 13-kt Little Boy device at Hiroshima on August 6, 1945. The Little Boy bomb was 10 ft long, 28 in. in diameter, and weighed 8,900 lb. Thus, the first nuclear explosion in combat occurred in a device that had never been tested. It was a gun-type system, where two subcritical masses were brought together by means of propellant to form a supercritical mass without compression. Initiation was by four polonium-beryllium neutron sources called Squab. [redacted]

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CROSSROADS

Although the two Operation Crossroads shots shed no new light on implosion design, they were a major effort that gave considerable weapons effects information. The first shot, Able (July 1, 1946), was an air-drop detonated 520 ft above the Bikini lagoon. The drop missed the desired target by about 700 yd. The second shot, Baker (July 25, 1946), was detonated 90 ft under the surface of the Bikini lagoon. The underwater shot proved so destructive that a third detonation at a greater underwater depth was canceled by President Harry S. Truman on September 7, 1946.

SANDSTONE

[redacted]

DOE
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The country had no permanent proving ground, and Eniwetok was picked on a one-time basis for Sandstone. [redacted] All were fired

DOE
b(3)

on 200-ft towers; all used the Urchin initiator.

The first of these was X-Ray, detonated on April 15, 1948, on the island of Enjebi. [redacted]

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[redacted]

DOE
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[redacted]

DOE
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[redacted]

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DOE
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[redacted]

DOE
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[redacted]

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DOE
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[redacted] Perhaps most important, Los Alamos had achieved these design improvements without the aid of all the internationally famous scientists who had populated Los Alamos during the war years. Operation Sandstone also led to the concept of developing Eniwetok as a nuclear proving ground.

STOCKPILE 1945–1950

At this point, it is interesting to look at the evolution of the national stockpile of nuclear weapons during the period 1945 to 1950. During 1945, 1946, and 1947, the only weapons in stockpile were copies of the Trinity system. After all, it was the only implosion system that had been tested. The numbers were quite small: 2 weapons in 1945, 9 in 1946, and 13 in 1947. Stockpile numbers are usually quoted as of the end of the fiscal year. Thus, the above numbers should be interpreted as 9 on June 30, 1946, and 13 on June 30, 1947. The meaning of the 2 in 1945 is not clear.

DOE
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[redacted] It is more probable that the two are as of December 31, 1945.

The early implosion weapons were made up of three components: the HE system, the pit, and the core. The pit was the metal assembly directly inside the HE. The core was a ball containing the fissile material [redacted]

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[redacted]

The number of delivery vehicles that were available is also interesting. During World War II, under the code name "Silverplate," 46 Boeing B-29 Superfortresses were modified to carry the Mk-3. However, after the war, their numbers diminished. By January 1946, there were 27 nuclear-capable B-29 aircraft and by December 31, 1946, only 23.

DOE
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[redacted]

As of March 1, 1948, the number of nuclear-capable B-29s had climbed to 35. By December 1, 1948, the number of nuclear-capable aircraft had risen to 50: 38 B-29s, 18 Boeing B-50s, and 4 Convair B-36 aircraft.

DOE
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[redacted]

[redacted]

DOE
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Thus, at the end of 1949, the stockpile stood at 170 weapons of 4.185 kt cumulative yield. [redacted]

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The year 1949 was critical because on September 23, 1949, President Truman announced to the nation that the Soviet Union had detonated an atomic bomb. The test was actually conducted on August 9, 1949. As of mid-January 1949, we had 121 nuclear-capable aircraft: 66 B-29s, 38 B-50s, and 17 B-36s.

[redacted]

DOE
b(3)

[redacted]

On January 1, 1950, we had 225 nuclear-capable aircraft: 95 B-29s, 96 B-50s, and 34 B-36s. As of July 1, 1950, there were 264 nuclear-capable aircraft, breakdown unknown.

RANGER

Following Sandstone in 1948, no further tests occurred until 1951, when a series of five tests was conducted in 11 days during January and February in Operation Ranger at the Nevada Proving Ground (NPG), later renamed the Nevada Test Site (NTS). [redacted]

DOE
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Because of the short time available, these tests could not be conducted overseas. A portion of the Las Vegas Bombing and Gunnery Range northwest of Las Vegas, Nevada, was selected for the tests. Yields had to be kept small because of possible hazards to surrounding communities. From the time of the concept of Operation Ranger, until its completion two months later, the total operational cost was about $83.5 million.

DOE b(3)

[redacted]

[redacted] All shots were air dropped over Frenchman Flat and detonated slightly more than 1,000 ft above the ground to minimize fallout. [redacted]

DOE b(3)

DOE b(3)

[redacted]

The first test, Ranger A, was fired January 27, 1951. [redacted]

DOE b(3)

[redacted]

DOE b(3)

[redacted]

The second test, Ranger B-1, was fired the next day, January 28, 1951. [redacted]

DOE b(3)

[redacted]

DOE b(3)

[redacted]

DOE b(3)

[redacted]

b(3)

DOE
b(3)

[redacted]

DOE
b(3)

[redacted] The relative ease and speed of execution of the Ranger series suggested that a permanent proving ground be established in Nevada.

GREENHOUSE

Action shifted to Eniwetok where Operation Greenhouse took place in April and May of 1951. [redacted]

DOE
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DOE
b(3)

[redacted] Dog was fired on a 300-ft tower on April 8, 1951, on Enjebi Island. [redacted]

The second shot of the Greenhouse series was Easy, detonated on April 21, 1951, on Runit Island. [redacted]

DOE
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DOE
b(3)

[redacted]

DoE
b(3

[redacted]

DoE
b(3)

The next test in sequence was George, detonated on Eleleron Island on May 9, 1951.

[redacted]

DoE
b(3)

The final event of the Greenhouse series was Item, detonated on Enjebi Island on May 25, 1951.

[redacted]

DoE
b(3)

DOE
b(3)

[redacted]

In going from Easy to Item, two steps had been taken. An all-oralloy core had been used rather than a composite. More important, the first attempt at boosting with DT gas had been very successful.

[redacted]

DOE
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BUSTER–JANGLE

The Buster–Jangle series was conducted at the NPG from October 22 to November 29, 1951. The Buster part of the series consisted of five shots that were predominantly weapons development, whereas the Jangle part of the series consisted of two weapons-effects shots that were primarily concerned with the effects of surface and underground nuclear explosions. In November 1950, the Atomic Energy Commission (AEC) notified the Department of Defense (DoD) that plans were under way to conduct nuclear weapons development tests to be called Operation Buster in the fall of 1951 at the NPG. On February 12, 1951, the Armed Forces Special Weapons Project (AFSWP) outlined military participation in the Buster tests to the Joint Chiefs of Staff (JCS). On March 8, 1951, AFSWP asked the Army, Navy, and Air Force to submit proposals for projects to be conducted during the Buster Operation.

Studies of the underwater detonation in operation Crossroads had led to questions concerning the effects and possible military value of an underground nuclear detonation. During 1950, the AEC and DoD looked for a suitable test site for an underground and a surface detonation that had been named Operation Jangle. They eventually selected Amchitka Island in the Aleutian Islands for the tests that were to be called Operation Windstorm and were to be conducted between September 15 and November 15, 1951. The JCS approved the site in late September 1950, and President Truman endorsed the plans for Operation Windstorm on November 30, 1950. After receiving proposals for projects from the services, the Research and Development Board recommended that the tests be conducted within the continental United States. On March 28, 1951, representatives of AFSWP, AEC, and JCS met and agreed that the tests should be conducted at the NPG. The two nuclear events were subsequently renamed Operation Jangle. Because Buster and Jangle were then both scheduled for the fall of 1951 at NPG, AFSWP recommended that the two series be combined and called Operation Buster–Jangle. This recommendation was approved by the AEC on June 19, 1951.

Troop exercises were conducted in connection with the Dog, Sugar, and Uncle shots of Buster–Jangle.

The first of the Buster–Jangle tests was [redacted] Able. [redacted]

DoE
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[redacted]

DOE
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[redacted]

DOE
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[redacted] Baker and the two succeeding shots were dropped from a B-50 aircraft 19,000 ft above the ground into Area 7 of NPG and detonated at slightly over 1,000 ft above the ground.

The next test was Charlie. [redacted]

DOE
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DOE b(3)

[redacted]

DOE b(3)

The next test was Dog.

DOE b(3)

[redacted]

DOE b(3)

The next test was Easy.

DOE b(3)

[redacted]

DOE b(3)

The Easy shot was dropped from a B-45 aircraft 24,000 ft above the ground into Area 7 of NPG and detonated about 1,300 ft above the ground.

DOE b(3)

[redacted]

[redacted]

DOE b(3)

The high level of test activity continued into 1952 with 2 test series and 10 tests.

STOCKPILE 1951

[redacted]

DOE b(3)

DOE b(3)

At this time, the Navy had 10 Lockheed P2V-3C Neptune Patrol bombers and 6 North American AJ-1 Savage attack bombers to deliver nuclear weapons. Both were modified to carry the Mk-8. In addition, the AJ-1 could carry the Mk-4 and subsequent bombs.

[redacted]

DOE b(3)

DOE b(3)

[redacted]

DOE b(3)

Confidence was returning in plutonium production because new reactors had gone on line at Hanford in 1949 and 1950.

The Russians detonated two nuclear tests in October 1951.

TUMBLER–SNAPPER

By August 1951, the AEC felt that it would probably conduct one or more tests during the spring of 1952, and the AFSWP so advised the services. In October 1951, the services recommended projects to be included in these tests. At about the same time, the AEC formally advised the DoD that it intended to conduct a nuclear-weapons testing series at the NPG beginning on May 1, 1952. On December 14, 1951, AFSWP recommended to the JCS that a series of tests be conducted, primarily to measure overpressure resulting from airbursts. On January 10, 1952, the JCS approved that recommendation. These tests were to be made before May 1, 1952, the beginning date for the AEC tests.

The Tumbler–Snapper series of eight tests was conducted at the NPG from April 1 to June 5, 1952. The Tumbler phase, of primary interest to the DoD, consisted of four weapons-effects shots: Able (TS-1), Baker (TS-2), Charlie (TS-3), and Dog (TS-4).

[redacted]

DOE b(3)

Shots Charlie and Dog were also part of the Snapper phase in that they employed experimental devices. Troop maneuvers were conducted in association with shots Charlie and Dog. The other weapons development tests of the Snapper Series, Easy (TS-5), Fox (TS-6), George (TS-7), and How (TS-8), were fired on 300-ft towers.

DOE b(3)

[redacted] Both were air drops from B-50 aircraft about 18,000 ft above the ground; TS-1 was detonated about 800 ft above the ground in Area 5 (Frenchman Lake) and TS-2 about 1,100 ft above the ground in Area 7 of NPG. The bomb missed the target by 43 m in Able and by 50 m in Baker. [redacted]

DOE b(3)

[redacted] TS-1 was detonated over a hard dry surface while TS-2 was detonated over a rough dusty surface. The effects were only slightly different.

Shot TS-3 was an air drop from a B-50 aircraft about 28,000 ft above the ground and detonated about 3,400 ft above the ground over a rough, dusty surface in Area 7 of NPG on April 22, 1952. The bomb was off target by 45 m. [redacted]

DOE b(3)

Shot TS-3 was open on a limited scale to the news media. They witnessed the detonation from News Nob, more than 15 km south of Ground Zero. [redacted]

DOE b(3)

Shot TS-4, [redacted] was air dropped on May 1, 1952, from a B-45 aircraft about 19,000 ft above the ground and detonated about 1,000 ft above the ground in Area 7. The bomb was 14 m off target.

DOE b(3)

[redacted]

DOE b(3)

DOE b(3)

DOE b(3)

[redacted]

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[redacted]

The AEC canceled a ninth detonation, a tower shot that had been scheduled to follow TS-8 by about one week, because the first eight tests had yielded sufficient data.

IVY

Operation Ivy at Eniwetok consisted of only two tests, but they were significant ones. The Ivy tests can be viewed as a U.S. response to the Russian detonation of a nuclear explosion. Mike, on November 1, 1952, was the first two-stage thermonuclear explosion detonated by the United States.

DOE
b(3)

[redacted]

Needless to say, it was a surface shot and was fired on the island of Eluklab. As a result of this shot, the island became the Mike Crater.

DOE
b(3

[redacted]

DOE
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[redacted]

DOE
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[redacted]

DOE
b(3)

[redacted]

DOE
b(3)

[redacted]

STOCKPILE 1952

DOE
b(3)

[redacted]

DOE
b(3)

[redacted]

In spite of the non-unique nature of the stockpile description, a total yield of 49,951 kt with an average yield of about 60 kt has been quoted in the DOE stockpile tabulation. [redacted]

DOE
b(3)

[redacted]

The lightest weight that can be found quoted for these systems either as a bomb or warhead are, 8,170 lb for the Mk-6, 2,405 lb for the Mk-5, 887 lb for the Mk-7, and only 650 lb for the Mk-12, which had not entered the stockpile. Nonetheless, a threshold had been crossed in 1952 with the availability of lighter-weight systems, thereby broadening the spectrum of possible delivery vehicles.

[redacted]

DOE
b(3)

E b(3)

[redacted] The British detonated their first nuclear explosion on October 3, 1952, on Monte Bello Island off the northwest coast of Australia.

SUMMARY

Development of implosion systems can be visualized by a genealogy chart (Fig. 1). It shows the progression from one test to another with the main changes indicated. Each test is designated by a circle with letters to identify the test (key in Table I). The number on the connecting arrow (keyed in Table II) tells the changes made after the test at the tail of the arrow to get to the test at the head of the arrow. The numerical sequence is keyed to the time sequence of the tests. A number of tests were educational and recognized as dead ends. [redacted]

DOE b(3)

These tests along with Item, the first DT gas boost, appear in retrospect to be the main advances after the first changes had been made in Operation Sandstone. Yields in the above test sequence progressed from 82.9 to 46.7 to 31.4 to 12.0 kt. [redacted]

DOE b(3)

Figure 2 shows the growth of stockpile numbers during the period 1945 to 1952, omitting the small number of gun-assembled weapons not easily displayed on the graph. It also shows the contribution of the individual HE systems to the total stockpile. Straight lines were drawn between year-end points.

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